A SENSITIVE MAGNETOCARDIOGRAPH FOR FETAL SURVEILLANCE

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***Abstract*-To use fetal magnetocardiography for diagnostic purposes, it is important to know the requirements for the instrument. One of the questions to be answered is how sensitive the fetal magnetocardiograph must be. In this paper the requirements will be discussed and a highly sensitive magnetocardiograph, that is optimized for fetal magneto-cardiography in a magnetically shielded room, will be presented.**
***Keywords*-fetal magnetocardiography, fetal arrhythmia**

I. INTRODUCTION

The fetal magnetocardiograph is intended to measure magnetic fields arising from currents generated in the fetal heart. These fields are extremely weak and can only be detected by means of a superconducting quantum interference device (SQUID) cooled by liquid helium. Usually, the mother is lying in supine position underneath the vessel (*i.e.* cryostat) containing the SQUID immersed in liquid helium, as illustrated in Fig. 1. Fetal magnetocardiograms (MCGs) can be measured reliably from the 20th week of gestation onward. However, customarily the data are averaged, because in the raw data often the P-wave and the T-wave are not discernible and the duration of the various waves cannot be extracted from the raw data. A signal can be averaged if the R-peak signal is clearly observable in the raw data and if enough heart cycli are measured that are correlated.

Fetal MCG can be used for the detection and classification of arrhythmias and the study of congenital heart diseases [1, 2]. Though others techniques do exist (fetal ECG, ultrasound), they either do not provide information about the electrophysiology of the fetal heart, the reliability is low, or they have a low resolution making it difficult to apply them for certain clinical applications.

The most common arrhythmia in a fetus are isolated extrasystoles. In order to diagnose them it is enough to measure the fetal heart rate with a beat-to-beat accuracy. The same is true for the diagnosis of tachycardia and bradycardia. To distinguish atrioventricular blocks in second- or third-degree ones, it is necessary to see the P-waves and the QRS-complexes in the raw data. The same is true for atrial flutter and extrasystoles (in order to be able to determine whether the extrasystoles have a ventricular or supraventricular origin). In our experience, the P-wave is somewhat larger in case of a heart block than in normals. This may be due to hypertrophy of the atria. Precise determination of the atrioventricular relationship in cases of supraventricular tachycardia is a major element on which the choice of an appropriate antiarrhythmic agent is based. All ultrasonographic approaches are overestimating the PR-interval because isometric contraction times and electromechanical delays are included. Moreover, the inaccuracy in the PR-interval determination is about 30 ms [3]. With fetal MCG it is possible to determine the PR-interval with an accuracy of 5 ms and the RR-interval with 2 ms. This requires that the fetal MCG should be recorded at several positions above the maternal abdomen because if the fetal MCG is recorded in only one position, the duration of the P-wave may be underestimated. The diagnosis of a prolonged QT-syndrome requires that the T-wave is discernable in the averaged data. To study congenital heart diseases, the duration of the P-wave, PR-interval, QRS-complex, QT-interval and T-wave should be available.

II. METHODS

The requirements for the fetal magnetocardiograph discussed above are summarized in Table 1. PAC stands for premature atrial contraction and PVC stands for premature ventricular contraction. The results shown imply that to cover most of the cases, the fetal magnetocardiograph must be so sensitive that P-waves can be observed in the raw data and that T-waves are discernible in the averaged fetal MCG. We have tried to meet the requirements by constructing a highly sensitive fetal magnetocardiograph. To ensure that the intrinsic noise of the system is low enough low-Tc DC SQUIDs were used [4]. The intrinsic noise level of the SQUIDs is lower than 10 $\mu\phi_0/\sqrt{Hz}$. The wire-wound first-order gradiometer, where each sensing coil has an area of 1.8 10^{-3} m^2, was coupled inductively to the SQUID washer. To measure the three components of the magnetic field three channels were implemented. The gradiometer is depicted in Fig. 2. The intrinsic noise of the system is about 2 fT/$\sqrt{Hz}$.

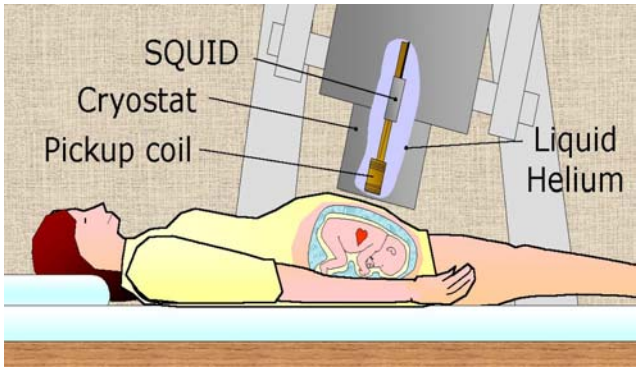

Fig. 1. Scheme of the fetal magnetcardiograph.

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Abstract

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TABLE I
REQUIREMENTS FOR FETAL MAGNETOCARDIOGRAPH

Problem	Nowadays diagnosed in	What to see in fetal MCG for diagnosis
Fetal heart rate	From the 10-12th week onward by means of Doppler ultrasound	R-peaks in raw signal
Atrial flutter	Third trimester by means of ultrasound	P-waves in raw signal (flutter-waves)
Fetal extrasystoles (PACs/PVCs)	Third trimester by means of ultrasound	P-waves and R-peaks in raw signal
Atrioventricular Block	Third trimester by means of ultrasound	P-waves and R-peaks in raw signal
Long QT syndrome	Postnatal by means of ECG	T-wave and R-peak in averaged signal
Congenital heart disease	Second trim1ester by means of ultrasound	PQRST complex in averaged signal

The noise has almost a white character within a bandwidth of 1-100 Hz with the exception of a narrow bandwidth around 50 Hz. In designing a magnetocardiograph of this level of sensitivity, the thermal noise generated by the cryostat becomes an important issue. We have chosen a low-noise cryostat to ensure that the SQUID noise is the only sensitivity-limiting factor. A drawback is that the helium consumption is rather high.

Fetal MCGs of women with an uncomplicated pregnancy were measured. Before each measurement, the fetal heart position was determined using ultrasound. The cryostat was positioned in several places above the maternal abdomen where the R-peak in the fetal MCG signal had the largest magnitude. The maternal ECG was recorded simultaneously, and was used as a trigger for the subtraction of the maternal MCG from the recorded signal.

III. RESULTS

Examples of averaged signals acquired at a gestational age of 35 and 21 weeks are depicted in Figs. 3A and 3B, respectively. The magnitudes (peak-to-peak) of the QRS complexes are 0.4 pT and 1.2 pT, respectively. The numbers of averaged complexes are 270 and 288. The P-wave and T-wave are discernible in the signals shown. These results would enable both the diagnosis and classification of an atrioventricular block as well as that of a prolonged QT syndrome. However, it is quite difficult to define the time instants of the beginning and ending of the P- and T-waves reliably. Moreover, the time instances may change significantly from patient to patient. For example, QT-intervals in Figs. 3A and 3B are different. Analysis of recordings has shown that a sensitivity of 2fT is enough to distinguish P-waves in raw signals acquired from normal patients. An example of the raw signal acquired from a normal patient after subtraction of the maternal MCG is depicted in Fig. 3C. The maternal ECG recorded

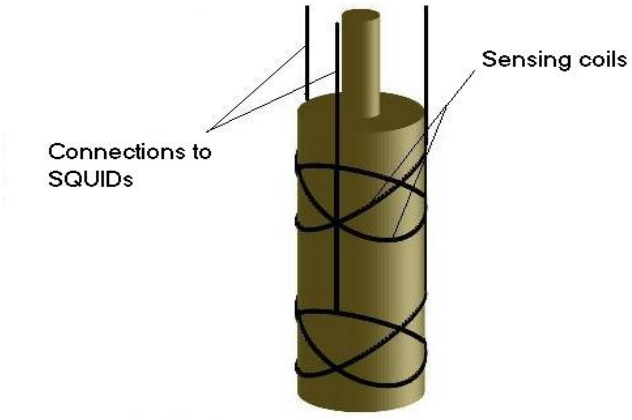

Fig. 2. The three-channel gradiometer. During measurements the axis of symmetry is perpendicular to the maternal abdomen.

simultaneously is shown in Fig. 3D. Comparison of the two plots leads to the conclusion that the maternal MCG was subtracted from the raw signal fairly well. The magnitude of the P-wave in this case was about 0.2 pT. The P-wave in an averaged signal measured from the same patient a few minutes later at a different location above the abdomen had a magnitude that was about ten times smaller.

IV. DISCUSSION

Magnitudes of the P-wave, QRS complex and the T-wave strongly depend on the position of the cryostat above the maternal abdomen and on the individual features of the pregnant woman like the depth of the fetal heart and the position of the fetus. This is why it is quite difficult to compare the strength of the waves in different recordings.

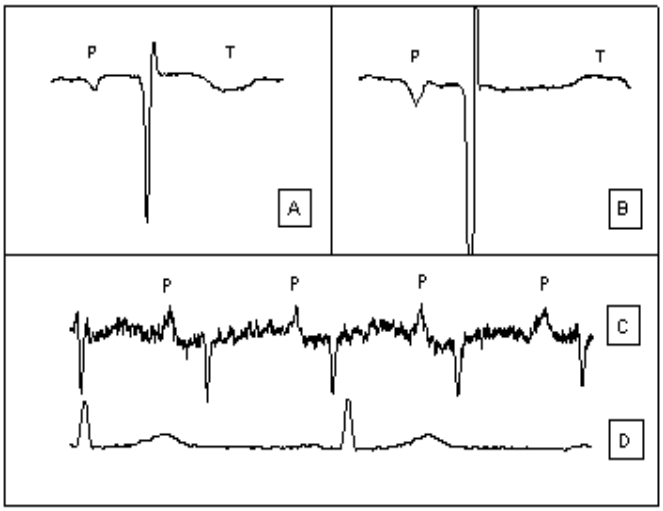

Fig. 3. Averaged signals acquired from volunteers with gestation period of 35(A) and 21(B) weeks. Raw signal from a normal fetus (C) simultaneously recorded with maternal ECG (D).

To overcome this problem, a fetal heart model and a model of the volume conductor must be developed, that would allow the computation of the relationship between the magnitudes observed and the heart activity. Although, P-waves may be observed in the raw signal, it is quite difficult to find the location, above the maternal abdomen, were the strength of the P-wave has the maximum value. The position could be found easily, if a multi-channel system is used. A drawback of the multi-channel system is that it is expensive. We may conclude that the requirements given in Table 1 are met by the fetal magnetocardiograph described.

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